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# Optimal design solutions for structures using ANSYS software

**N I Marchuk, S V Deordiev and E V Prasolenko**

Siberian Federal University 82 Pr. Svobodny, Krasnoyarsk, 660041 Russia

t9131708548@gmail.com

**Abstract.** In this paper we considered the solution of a design complex problem of the frame members of an industrial building on the basis of an algorithm for the rational design of structure suggested in using ANSYS Workbench Platform. As a result, we achieved constructions of optimal volume.

## 1. Introduction

When it comes to the design of buildings and constructions' structural frame, the priority requirements are strength, stiffness, and stability. At the same time, development of effective structural members with proper bearing capacity and optimal size is an essential problem for designing rational and cost-efficient constructions.

Various options of generic algorithms, the theory of adaptive optimization, topological optimization and other means [2-6] are applied to solve this problem. Applying members of topological and parametric optimization for design of optimal construction projects is extensively used in different spheres of technology, mechanical engineering, aircraft engineering, instrument engineering, and construction [7-10].

The objective was to test the algorithm for the rational design of structures [1] for typical construction objects using the case of a problem of optimization of load bearing structures for an industrial building.

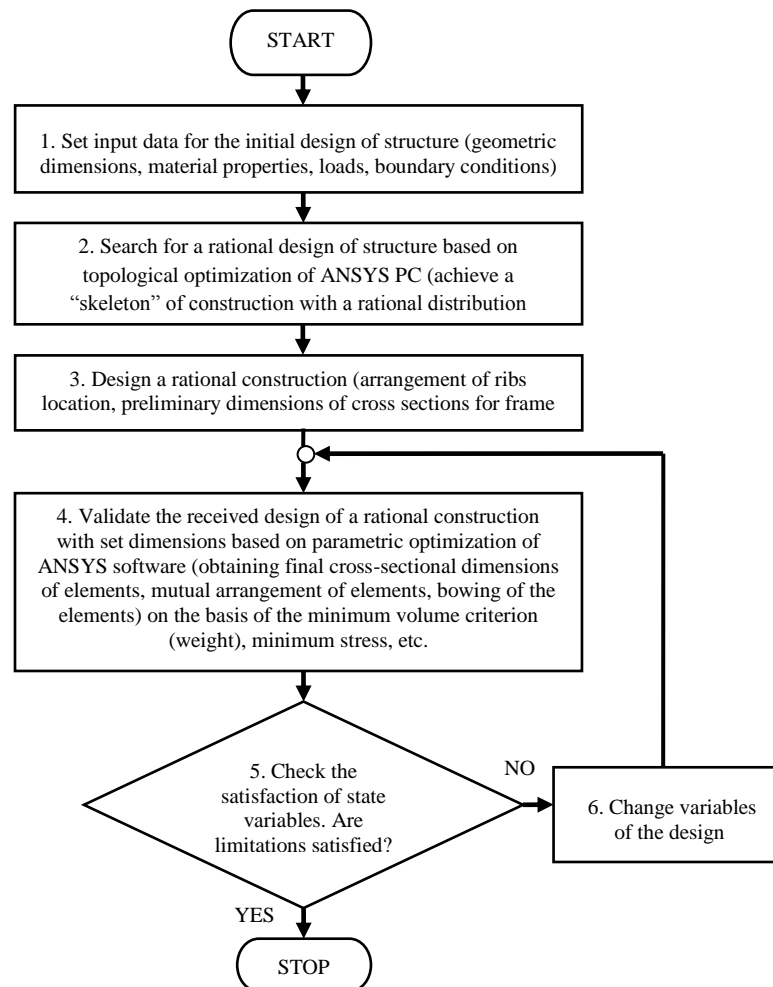
## 2. Problem setup and methods

In order to use the algorithm (Figure 1), as an example of optimal construction design we will solve a problem of complex optimization for a block of a single-storey industrial building with a length of 72m, two spans of 24m and 18m, a centre-to-centre distance of 6m edge columns and central columns of 12m.

The initial data are based on geometrical dimensions and supporting members' cross-section of the building and are taken from [11]. Columns are height 11.6 m, width of the bottom 1.2 m, of the top 0.6 m; secondary truss 24x3 m; principal truss 18x2.5 m; roof slabs: dimensions 6x3 m, thickness 0.2 m. Frames are joined together by solid vertical plates.

The block of the building was calculated considering the load including the own weight of the structures as well as snow, wind and crane loads. At the beginning, we solved the problem of topological optimization for vertical plates imitating vertical bracing between the frames. In this case, the columns, trusses and roof slabs belonged to the non-optimized area. The plates were approximated by a finite element of PLANE 82. We used the element BEAM 189 to approximate columns and trusses and the element SHELL 93 for the roof slabs. The vertical plates were made of metal; all other constructions were made of concrete B25.





**Figure 1.** The enlarged block diagram of the algorithm for the rational design of structures.

For the correct solution of the problem to topological optimization in accordance with the source [2], it is recommended to approximate the investigated zone of the construction with a dense grid. In the problems considered, the bar spacing along the full length of finite element grid was 0.02-0.05 m.

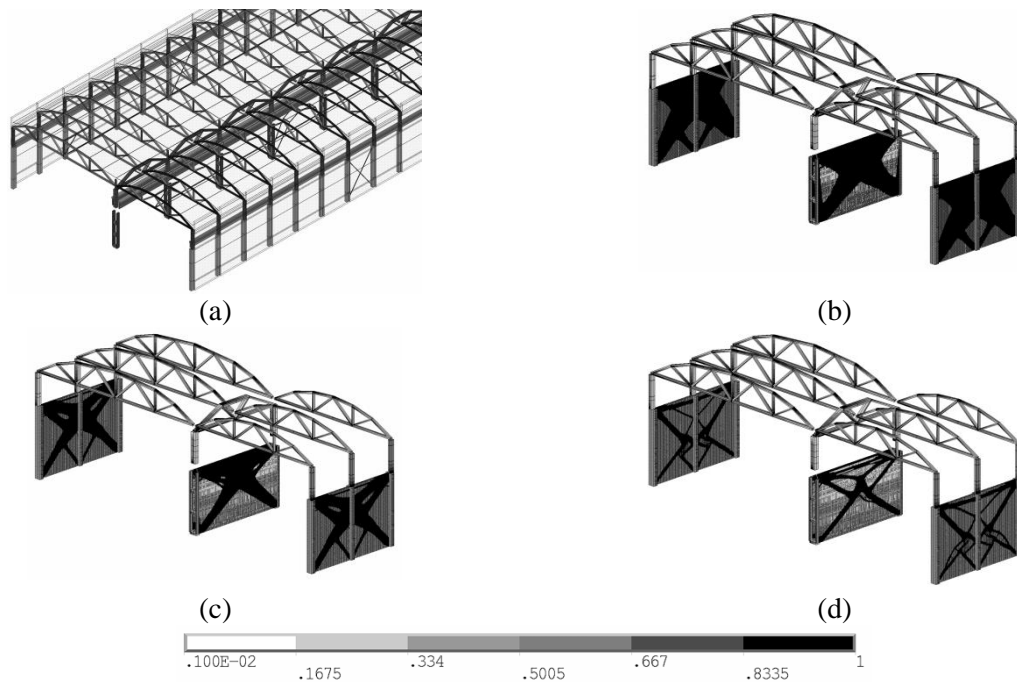
It was assumed to achieve maximum structural rigidity for a given reduction in the amount of material as a criterion for topological optimization.

### 3. Results and discussions

The optimization results are presented as topological shapes (Figure 2, the darkest background corresponds to the highest density of the material, the lightest to the lowest density and to the lack of material) with a decrease in the volume of the plate members from 30% to 70%.

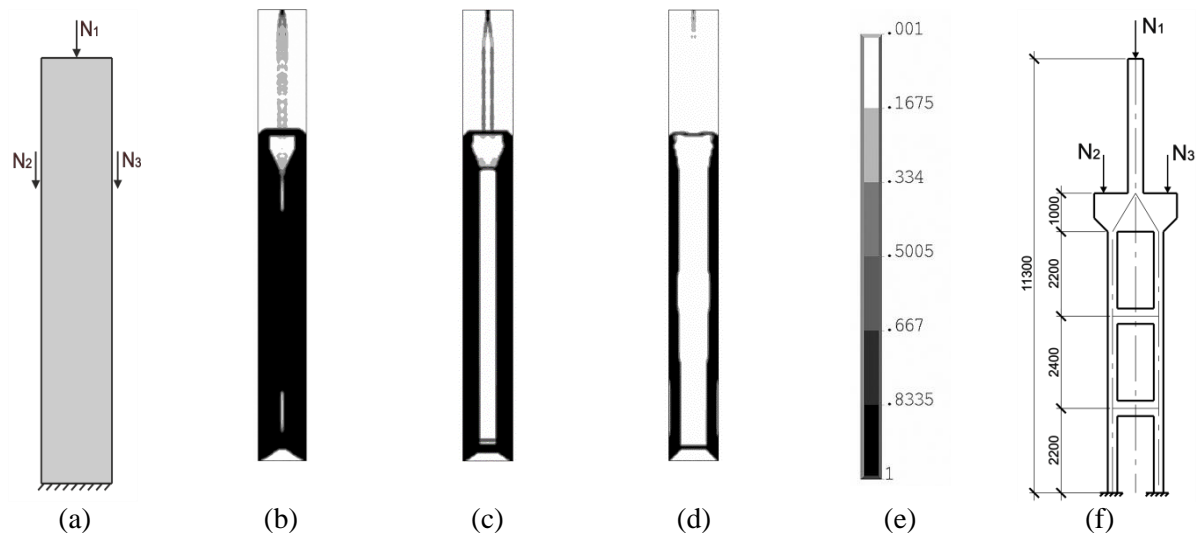
Comparison of the obtained topological shapes with the vertical bracing construction between the frames of a typical industrial building shows that the topological shape corresponding to a reduction in the amount of material by 70% (Figure 2 (d)) is closest to the actual construction.

At the subsequent stages, we solved topological optimization problems separately for the middle column, secondary one, roof trusses and roof slabs. The column was designed considering the constant load effect of the roof and trusses weight, the mass of crane beams and gantry rails, snow and the maximum pressure of cranes.



**Figure 2.** The block frame of an industrial building: (a) – the structural design; (b) – the topological vertical elements' shapes of the building's frame part, which model vertical bracing between the frames with a volume reduction of 30%; (c) - of 50%; (d) - of 70%.

The obtained results of topological optimization (Figure 3) showed that the real column was best matched to the topological shape with a reduction in the volume of material by 50%.

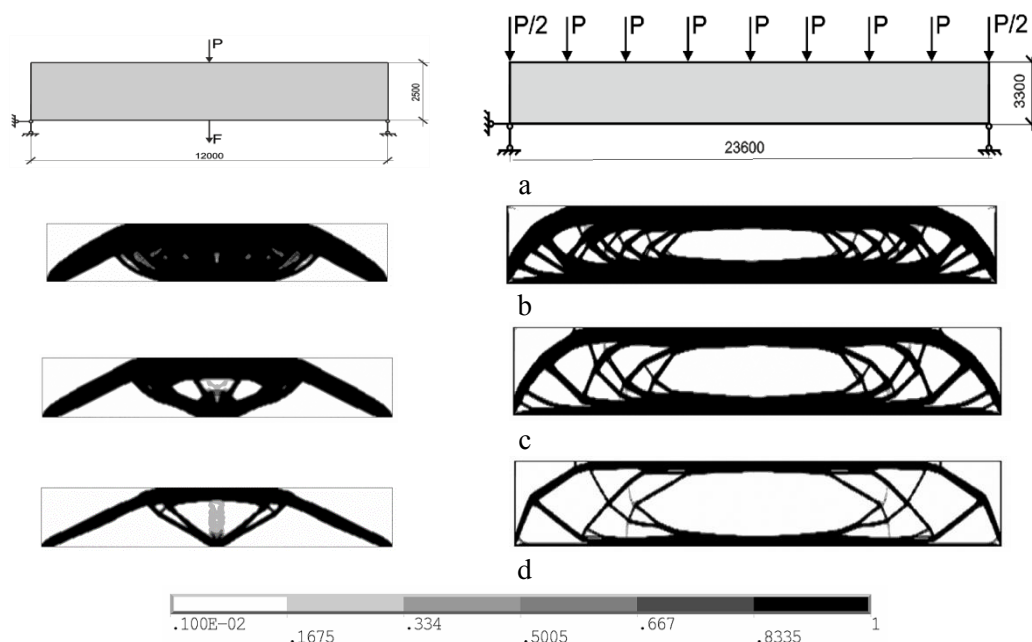


**Figure 3.** The column of an industrial building: (a) - structural design of the column with applied concentrated forces  $N_1, N_2, N_3$ , arising from the existing loads; (b), (c), (d) – the topological shapes with a decrease in volume by 30%, 50%, 70% respectively; (e) – the standard column structure of an industrial building [11].

As shaping members for secondary one and roof trusses we considered deep beams. We performed topological optimization under the specified loads from roof slabs, the weight of trusses and snow load

applied to trusses nodes and achieved topological shapes corresponding to a decrease in the volume of the material from 30% to 70% (Figure 4).

The achieved topological shapes form trussed frame structures that, depending on the set value of volume reduction, are close to trusses corresponding to the external load application scheme. The best approximation to the real truss structure from the considered projects is the topological shape with a volume reduction of 70%.



**Figure 4.** (a) - design diagram for the secondary and roof trusses with applied nodal forces  $P$  and  $F$ , arising from the existing loads; (b), (c), (d) – the topological shapes of trusses with a decrease in volume by 30%, 50%, and 70% respectively.

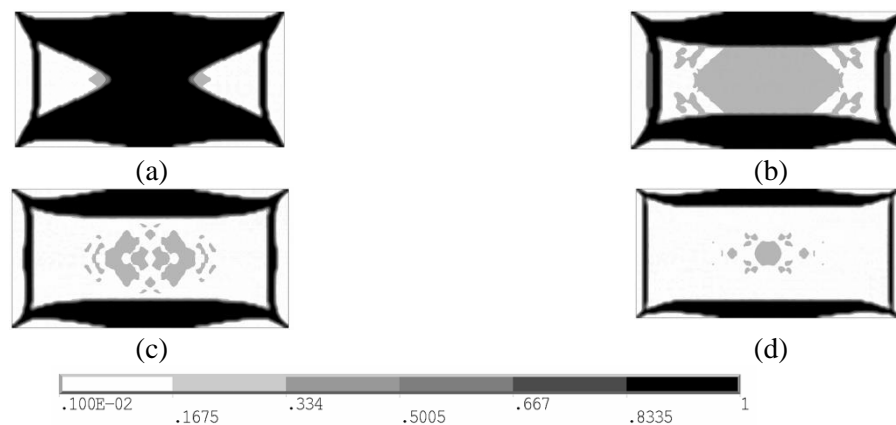
We set an initial design of the roof slab as a solid slab of 6x3 m dimensions and 0.2 m thickness, with hinged edges and being under the ultimate dead load of the roof weight and snow.

The criterion of topological optimization as in previous problems was achieving maximum rigidity for a given reduction from 30% to 70% of the volume of the material amount.

The places with the largest and smallest distribution of the material are clear on the achieved slab designs, that means that the frame ("skeleton") of the achieved structure, corresponding to the load and bounding actions as you can see from the topological shapes (Figure 5). At the same time, the most structured (clear zones with the most demanded material as places for setting ribs) floor slab projects with a specified reduction in material volume from 60% to 70%.

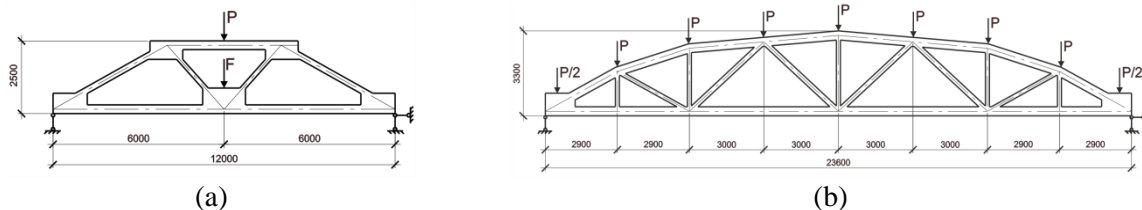
The supporting members (columns, a secondary truss, a roof truss and a roof slab, the frame latter being a slab supported by longitudinal and transverse ribs) of the industrial building have been designed with the use of the topological optimization results obtained in the form of the topological structural diagrams. At the same time, we assigned the dimensions of the column elements' cross-sections, roof slab, and trusses.

The cross-sections of the column: the lower stanchion 0.3 x 0.6 m and 0.3 x 0.6 m, the upper stanchion 0.7 x 0.6 m (Figure 3 (e)). The cross-sections of the secondary truss elements: the bottom chord 0.25x0.55 m, the top chord 0.4x0.55 m, the braces 0.25x0.55 m, (Figure 6 (a)). The cross-sections of the roof truss elements: the bottom chord 0,35x0,35 m, the top chord 0,35x0,35 m, vertical members and support bracing 0,25x0,2 m, braces in the span 0,16x0,2 m (Figure 6 (b)).



**Figure 5.** The topological shapes of the roof slab with a decrease in volume: (a) - by 30%, (b) - by 50%, (c) - by 60%, (d) - by 70%.

The cross-sections of the ribbed slab: the slab thickness is assumed equal to 0.1 m, the height of the longitudinal ribs is 0.3 m, their width is 0.15 m, the height of the transverse ribs is 0.2 m, and their width is 0.1 m. After industrial building members designing, we carried out a preliminary analysis of each member for the actual load.



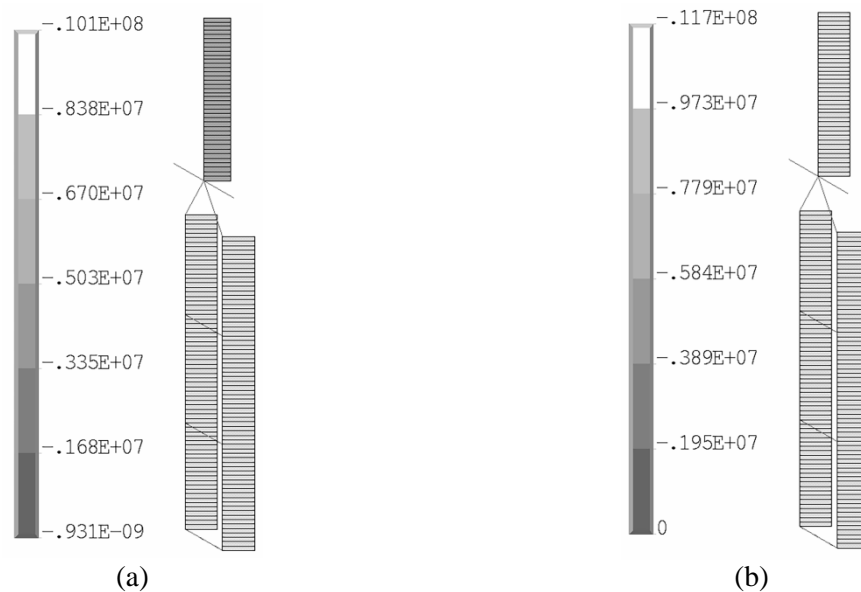
**Figure 6.** Structures of the trusses designed subject to the results of topological optimizing: (a) - the secondary truss; (b) - the roof truss.

The obtained results showed that the considered members are understressed (Figures 7 (a), 8 (a), 9 (a)) and there are reserves for reducing their dimensions. We performed a parametric optimization to obtain the final and optimal, in terms of dimensions, projects of the column, ribbed slab, secondary and roof trusses, meanwhile choosing minimization of their dimensions as an objective function.

The optimization parameters: for the column, the members' cross-section height of the bottom  $h_1$ ,  $h_2$  and top  $h_3$  stanchions; of the secondary and roof trusses - the members' cross-sectional areas of the top  $A_1$  and bottom  $A_2$  chords; for the slabs - the slab thickness  $h_1$ , the height of longitudinal  $h_2$  and transverse  $h_3$  ribs, respectively. The limitations are as follows: for the column by compressive stresses: 11.5 MPa; for the secondary and roof trusses by the maximum deflection: 0.012 m and 0.025 m, by maximum stresses for the compressed top chord: 17 MPa, by the critical tensile strains in the bottom chord: 0.003; in the ribbed slab by the deflection: 0.01 m, by the main compressive stresses in the slab and compressive stresses in the ribs: 11.5 MPa.

The minimum tolerated values of the cross-sections for the lower stanchion of the column are 0.25x0.5 m and 0.25x0.5 m, and 0.6x0.5 m for the upper stanchion; for the secondary and roof trusses: the lower chord is 0.2x0.55 m and 0.2x0.2 m, the upper belt is 0.25x0.55 m and 0.2x0.2 m, the braces are 0.2x0.55 m; for the slab thickness equal to 0.03 m, the height and width of the longitudinal ribs will be 0.2 m and 0.1 m, the transverse ribs will be 0.1 m and 0.05 m.

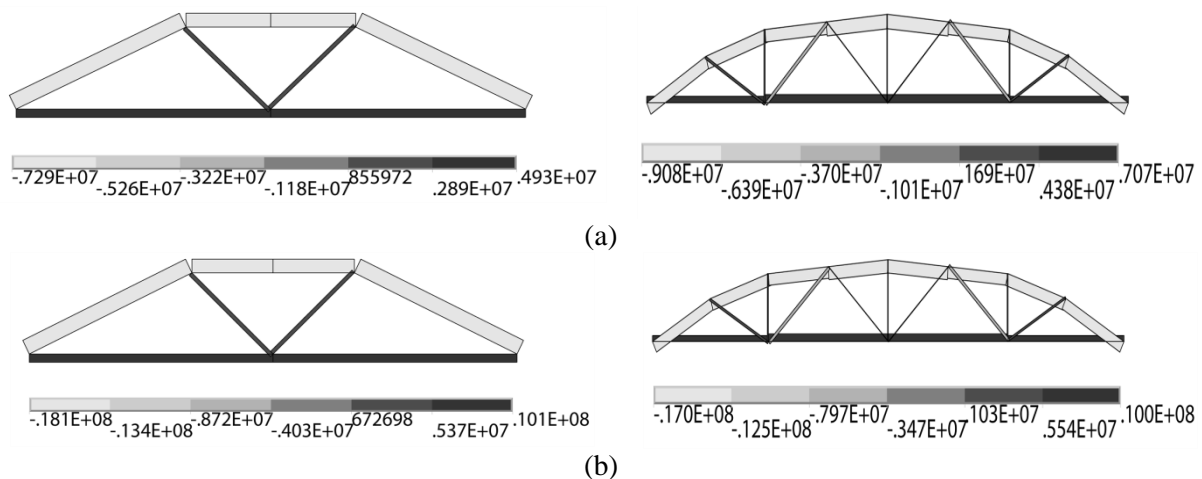
The results of the parametric optimization in the form of stress diagrams and isofields are shown in Figures 7 (b), 8 (b), 9 (b).



**Figure 7.** The compressive stresses (Pa) in the middle column: (a) - of the initial project; (b) - of the optimal project.

The final values of the cross-sections for the lower stanchion of the column were 0.26x0.51 m and 0.26x0.51 m, the upper stanchion 0.6x0.51 m. The maximum equivalent stress was 11.7 MPa. At the same time, the economy cut of the column material was 9.4%.

The final values of the roof truss upper and lower stanchions' cross-sections are 0.29x0.55 m, 0.21x0.55 m, of the secondary truss 0.25x0.25 m and 0.25x0.25 m.

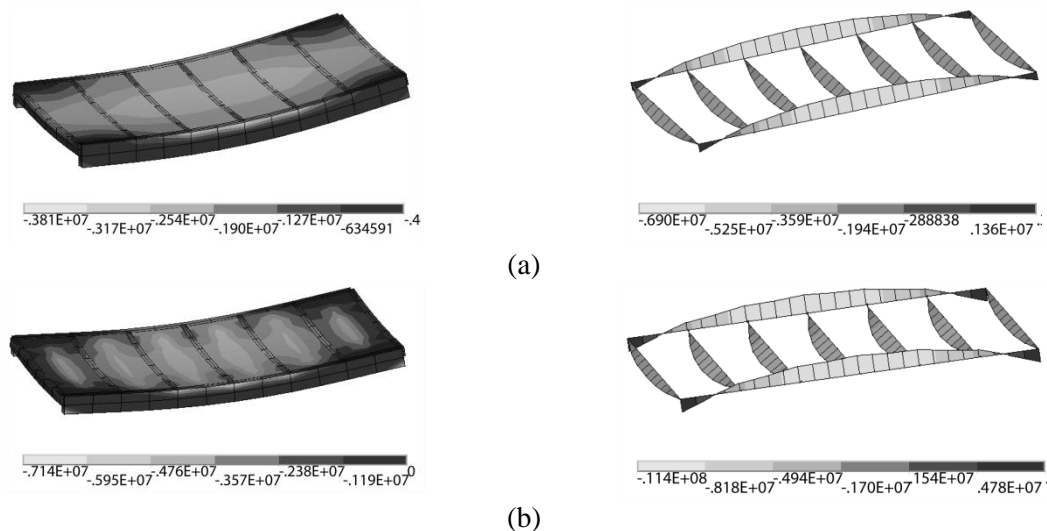


**Figure 8.** Compressive stresses (Pa) of the secondary truss and the roof truss: (a) - the initial project; (b) - the optimal project.

The maximum compressive stresses in the upper stanchion of the secondary truss reached 18.1 MPa, and 17 MPa in the roof truss. The maximum deflection of the secondary and roof trusses was respectively 0.0132 m and 0.026 m.

Moreover, the volume of the secondary truss decreased from 3.54 m<sup>3</sup> to 1.71 m<sup>3</sup>, and the roof truss was reduced from 8.18 m<sup>3</sup> to 5.66 m<sup>3</sup>. The maximum compressive stress in the ribbed slab was

11.4 MPa. The optimal design volume of the ribbed slab equals to 1.45 m<sup>3</sup> when the initial volume was 2.94 m<sup>3</sup>.



**Figure 9.** The main compressive stresses (Pa) in the slab and the compressive stresses in the ribs of the slab: (a) - the initial project; (b) - the optimal project.

#### 4. Conclusions

Using the algorithm of complex optimization [1] which is based on a combination of topological and parametric optimization methods based on the ANSYS software, we obtained the optimal design results of the load bearing members of the industrial building frame.

With the application of the design algorithm, we can solve similar problems for determining the rational design of structures, obtained through a developed series of industrial building and structures, and reduce the cost for design options. The resulting designs of load-bearing constructions have maximum hardness with a minimum amount of material that determines the cross-sections of the elements with a load bearing capacity in accordance with the requirement of design standards.

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